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Process Simulation Method for Product-Service Systems Design

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Abstract

In manufacturing, systems combining physical products and services have been attracting much attention. For such systems, designers need to consider values for customers as well as its economic cost. However, services include many stochastic elements because they are severely affected by human behaviors and interaction between humans. Therefore, parameters that affect the economic cost, such as working time and number of operation, vary because of the influence of the stochastic elements. In order to evaluate design solution from the viewpoint of the economic cost, this study proposes a service cost simulation method in consideration of stochastic elements in the service.

Keywords: Product-Service Systems; Service Engineering; Design; Process Simulation; Cost Engineering

1. Introduction

Environmental problems have grown in importance over the last couple of decades. Consequently, society should reduce the production and consumption volumes of artifacts to an adequate, manageable size without decreasing the current quality of life. To this end, it would be effective to pursue qualitative satisfaction rather than quantitative sufficiency and thus decouple economic growth from material and energy consumption [1]. For this purpose, manufacturing companies are starting to recognize that services and knowledge provided through a product are more important than the product itself [2]. As a result, “Product-Service Systems (PSS)” [3-5], which create value by coupling a physical product and a service, have been attracting attention.

According to this background, the authors of this paper have conducted conceptual research on design services from the viewpoint of engineering. This series of research studies is called Service Engineering [6-8]. Its objective is to provide a fundamental understanding of services as well as concrete engineering methodologies that can be used to design and evaluate services. In the design methodology proposed in Service Engineering, the design target represents customer value, and therefore, the design process includes the procedures to understand a target customer and to extract his/her requirements. In addition, in order to achieve a successful service, designers need to consider value for customers as well as its economic cost. In particular, most of the economic cost that is spent on the service offering is determined in the early stages of design, and therefore it is crucial for designers to design solutions from the viewpoint of economic cost. However, services include many stochastic elements because they are severely affected by human behavior and interactions between people. Therefore, parameters that affect the economic cost, such as working time and number of operations, vary because of the influence of the stochastic elements.

In order for designers to evaluate design solutions from the viewpoint of the economic cost, this study proposes a service cost simulation method in consideration of stochastic elements within the service. The effectiveness of this method is demonstrated by its application to an elevator operating service.

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2. Service Process Design

In order to represent a process that realizes customer values, in Service Engineering, a sub-model called an extended service blueprint is proposed [9].

The extended service blueprint consists of an interrelated activity blueprint and behavior blueprint. Both service activities and product behaviors are processes that produce services; service activities are tasks performed by humanware and related software, and product behaviors are tasks performed by hardware and related software.

The activity blueprint is based on a blueprint by Shostack [10] and illustrates the activity-oriented aspects of a service. The activity blueprint specifies the service delivery process and the interactions between the customer and the provider. On the other hand, the behavior blueprint specifies the physical processes needed to realize service functions.

In addition, there is an interrelation between the behavior blueprint and the activity blueprint. The extended service blueprint shows two types of collaboration between the two blueprints. The first type of collaboration involves an interaction between the customer and the product hardware, while the second involves interactions between the staff and the equipment or facilities. Information about such collaborations and service delivery denotes how the products are used, which is useful for product design.

3. Service Cost Simulation

3.1. Approach of this study

In the proposed simulation, a management accounting method known as Activity-Based Costing (ABC) [11] is applied to evaluate the economic cost of each activity in the service process. In addition, scene transition nets (STN) [12-13] is used as a simulation tool. STN is a very useful graphical modeling and simulation method for application to discrete-continuous hybrid systems based on the concept of Petri nets. In the following sections, ABC and STN are introduced, and then, the procedure for service cost simulation is proposed.

Activity-Based Costing (ABC)

ABC is a costing methodology used to trace overhead costs for cost objects such as products, processes, and departments [11]. In ABC, the resource costs, which include the overhead costs, can be allocated to the cost objects based on the activities. Activities are the operations needed to implement tasks, and resources such as labor, electricity, and facilities are consumed to perform the activities. For example, in order to deliver a product, activities such as designing, assembly, and shipping are essential. Moreover, for these activities, the abovementioned resources are consumed.

The ABC procedure consists of two stages (see Fig 1). In the first stage, the resource costs are associated with activities based on a cost driver. A cost driver is the criterion for cost allocation. In order to appropriately assign the resource cost to each activity, cost drivers have to be appropriately identified for each resource. For instance, the resource 'salary' may be driven by the amount of time the employee spends on an activity. In the second stage, costs are allocated to the cost objects instead of activities based on the number of activities the cost objects consume. This stage can be achieved by using cost drivers in a similar way to the previous stage. Thus, ABC calculates the economic costs by allocating resource costs for activities.

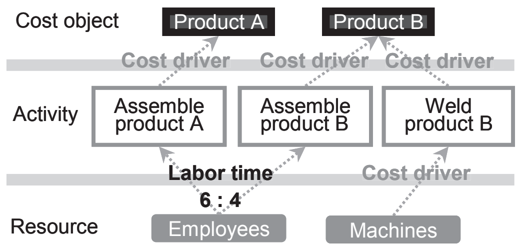

Fig. 1. Procedure of Activity-Based Costing [11]

Scene transition nets (STN)

Scene transition nets (STN) is a graphic modeling method for discrete-continuous hybrid systems; it uses the concept of "actors" and "scenes" [12-13]. It is based on the Petri net, which is a modeling method for discrete event systems. It can express hybrid systems by using the concept of a Petri net and by inputting differential equations into scenes. In STN, an actor corresponds to a subsystem of a hybrid system. Designers can simulate interactions between the subsystems that act in parallel by describing the models using object-oriented programming languages (e.g. Smalltalk, JAVA). STN consists of actors, scenes, transitions, and arcs, as shown in Fig 2.

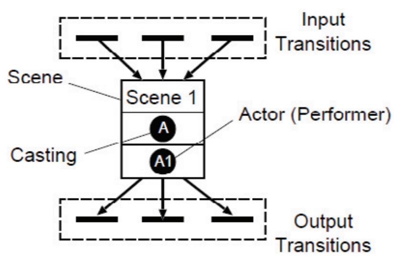

Fig. 2. Components of scene transition nets [12-13]

Actors in an STN correspond to the tokens in a Petri net. However, unlike tokens, actors have state variables whose values change dynamically. Scenes in an STN correspond to places in a Petri net. In an STN, scenes are combinations of activities defined in discrete event systems and dynamics for changing variables of actors in the activities. Transitions in an STN correspond to those in a Petri net and indicate scene transition boundaries that correspond to events in discrete event systems. Transitions and scenes are connected by arcs.

3.2. Procedure for service cost simulation

Step1: service process design

The service cost simulation begins with a service process design. In particular, designers develop the extended service blueprint that consists of an interrelated activity blueprint and behavior blueprint. For the development of the extended service blueprint, first, the designers extract customer requirements, and then, develop functions that realize these customer requirements. Next, the designers specify entities that actualize these functions. The entities include not only physical products but also facilities, employees, and information systems. Finally, the designers develop service activities and/or product behaviors are performed by the entities.

Step2: Estimation of entity cost

Table 1. Classification of cost elements in entity cost table

General costs	Detail costs	Explanation (general cost)
Personnel	White-collar worker	The costs any payment made to human activities
	Blue-collar worker	
	Operators	
	Worker involved in the performance of computer-based tasks	
Energy	Gas	The usage costs of service public utilities
	Water	
	Electricity	
	Others	
Material	Ingredient	The costs of any payment made to purchase the materials
	Expendable	
	Component	
Depreciation	Equipment	The costs of loss monetary value of physical environment
	Facility	
	Layout	
Others	Other categories	Other than above costs

Next, designers estimate entity costs that are spent for performing service activities and/or product behaviors. In order to support the designers to determine the entity costs, this study proposes an entity cost table. This cost table enables designers to identify the cost elements by using the encompassing cost classification. A cost element is a basic constituent and/or a physical composition that is consumed by an entity for realizing the service activities and/or product behaviors. In the entity cost table, as shown in Table 1, the encompassing classification of each cost element is structured as the sequence of general cost to the detail cost.

In detail, the general costs are classified into five elements: personnel, energy, material, depreciation and others. Each general cost element consists of various detail costs. For example, the personnel cost element consists of white-collar worker, blue-collar worker, operator and worker involved in the performance of computer-based tasks. The energy cost element consists of gas, water, and electricity. The material cost element consists of ingredient, expandable and component. In reality, the ingredient is the raw material used to transform into a finished good. The expendable is a consumable and the component is an item used for a certain period. These three materials are used to support the activity. The depreciation cost element consists of equipment, facility and layout. In fact, the equipment is a hardware or system controlled/utilized by an employee. The facility is equipment which could also be utilized by the customer. The others cost elements do not consist of specific detail costs. Finally, this encompassing classification of cost elements enables the service designers to determine the entity costs by selecting the relevant detail costs.

For determining the entity costs, first the designers identify the cost elements consumed by the entity with reference to the encompassing cost classification in the cost table.

Step3: Determination of cost drivers for each entity

In order to estimate the economic cost of each activity in the service process, in this step, the designers determine cost drivers that represent the criterion for cost allocation.

In the ABC method [11], the cost driver must be appropriately defined according to what the cost element is spent on for the work activity. Further, the parameter of this resource cost driver must be quantitative in order to calculate the volume of resource consumption. On the other hand, in engineering, a “unit” is the key element of engineering analysis and it is also the way of quantifying the underlying concept of dimensions. In the SI base units [14], which are commonly applied for any engineering calculations and/or scientific measurements, the basic units are classified based on the seven dimensions: length, mass, time, electric current, temperature, quantity of matter and luminous intensity.

Based on the ABC method, the cost drivers are represented by the SI base units. In this paper, as the basic units of the resource cost drivers, we suggest five dimensions of SI units based on the most frequent measurements for the cost elements in a service. The five SI dimensions consist of length, mass, time, quantity of matter and electric current, as shown in Table 2.

Table 2. Suggestion of cost drivers based on SI base dimensions

General costs	Detail costs	Suggestion of cost drivers (○)				
		Length	Mass	Time	Quantity of matter	Electric current
Personnel	White-collar worker			○		
	Blue-collar worker			○		
	Operators			○		
	Worker involved in the performance of computer-based tasks			○		
Energy	Gas		○			
	Water		○			
	Electricity			○		○
Material	Ingredient		○			
	Expendable				○	
	Component				○	
Depreciation	Layout	○				

According to the five SI dimensions, service designers determine a unit that corresponds to a cost driver. The cost driver of length is suggested for allocating the detail cost of “layout”. For example, production space/distance is frequently occupied by an operator, and therefore the unit for calculating the resource consumption of the production space/distance is “area”. The cost driver of mass is suggested for allocating the detail costs consisting of “gas, water and ingredient”. For example, gas and water are public utilities and ingredient could be coffee beans or raw meat. Thus, the unit for calculating the resource consumption of gas or water is “volume”; the unit for the ingredient is “weight”. The cost driver of time is suggested for allocating the detail costs consisting of “white-collar worker, blue-collar worker, operator, worker involved in the performance of computer-based tasks and electricity”. For example, manpower expenses are frequently measured by the work duration. The electricity cost is frequently measured by the kilowatt-hour. Thus, the unit for calculating the resource consumption of the manpower expenses or electricity is “hour”. The watt is used for electrical energy measurement. The cost driver of quantity of matter is suggested for allocating the detail costs consisting of “expendable and component”. For example, the expendable could be kitchen paper and the component could be kitchen tool. Thus, the unit for calculating the resource consumption of the expendable or component is “quantity”. The cost driver of electric current is suggested for allocating the detail cost consisting of “electricity”. For example, electricity cost is frequently measured by the kilowatt-hour, thus, the unit for calculating the resource consumption of the electricity is “watt”. Therefore, these suggested dimensions of SI units enable the service designers to determine the cost driver in accordance with the detail cost and general cost of each entity.

Step 4: Modeling the variability of a cost driver

Finally, for the service cost simulation, the designers construct a simulation model based on the components of STN. In this study, scenes correspond to service activities and product behaviors; the actors correspond to entities. Variables of actors, therefore, are defined as the cost drivers of the entities.

In this study, the variability of a cost driver is represented as a dynamic model. Services include many stochastic elements because they are severely affected by human behaviors and interactions between people. As a result, the cost drivers, such as working time and number of operations, vary because of the influence of the stochastic elements. Therefore, it is necessary to include stochastic elements in the STN models in order to simulate them exactly. In STN, designers can input functions that generate random real numbers in scenes and can easily simulate the service process including various stochastic elements (for example, action selections of actors may be simulated using a Boltzmann distribution or roulette selection method, and generation of noise may be based on a normal distribution, etc.). In the method, the designers construct some dynamic models of the variability of a cost driver by using differential equations, and set the equations into the relevant scenes. Finally, the service cost is simulated based on the variability of the cost driver.

4. Application

In this chapter, the proposed method is applied to an elevator operating service. In this application, in particular, the economic cost for an emergency response is simulated.

First, the extended blueprint for the emergency response was developed. Fig 3 mainly shows the user actions of using an elevator and the service activities that occur when an earthquake or fire is detected. These service activities are performed from beginning to end via interactions between actors. In an emergency, these activities start when the elevator experiences an emergency stop. The user calls on the intercom and the elevator company receives the call. The staff of the elevator company watches the user while checking images from the monitoring camera in the elevator. Then, the staff of the security company dash to the elevator and cope with the emergency after being contacted by the elevator company.

Next, the costs of the entities described in the extended blueprint were estimated by using the entity cost table. The designers determined the detail costs with reference to the cost information. For the representation of the entity costs, these detail costs were grouped into the general costs. Table 3 (a) shows the results of the entity costs. For example, the entity cost of maintenance

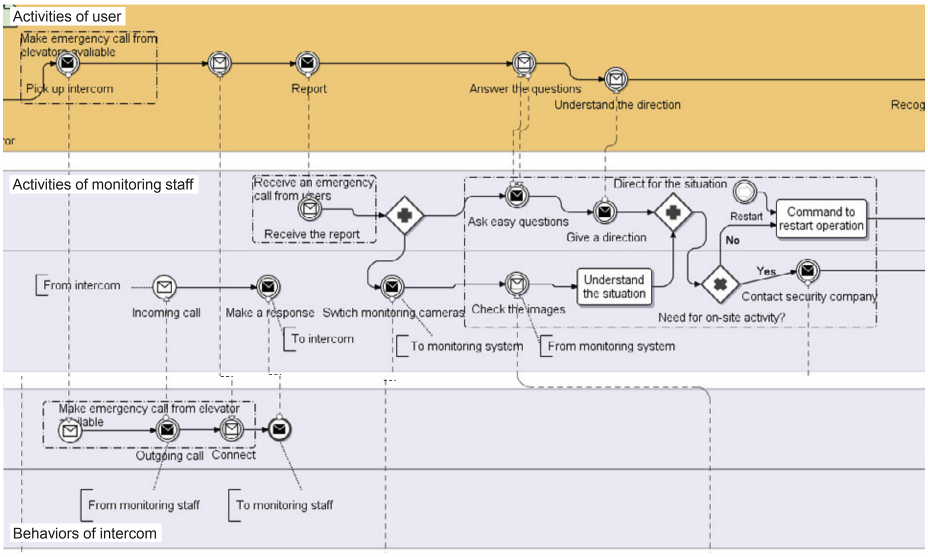

Fig. 3. Extended service blueprint for the emergency response in an elevator operating service

staff consists of personnel cost, energy cost and other cost.

In order to estimate the economic cost of each activity in the service process, the designers subsequently determined the cost drivers as the criteria for cost allocation. The designers determined several cost drivers with reference to the suggested dimensions of SI units. Table 3 (b) shows the results of the determination of the cost drivers. For example, as the cost drivers for the entity cost of maintenance staff, the designers determined the three drivers: time, quantity and length.

Finally, for the service cost simulation, the designers construct a simulation model based on the components of STN. Scenes were constructed in accordance with service activities and product behaviors in the extended blueprint. In each scene, the entity that performs relevant service activities or product behaviors was represented as the actor. For example, as shown in Fig 4, for the scene 'Understand' that represents the activity 'Understand the situation', the entity 'Monitoring staff' performing the activity was represented as the actor. As variables of these actors, the designers defined the cost drivers of the entities that were determined in the previous step. Some dynamics models of the variability of a cost driver were constructed.

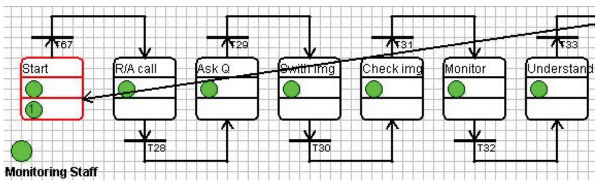

Fig. 4. An example of the constructed simulation model in STN

Table 3. Results of entity costs and activity costs

Entity	Activity	Total ($/year) (a)	Resource cost driver (b)	Enable the comunication	Receive and answer the call	Ask the user questions	Enable the monitoring	Switch the image	Check the image	Monitor the inside elevator
Maintenance staff	Personnel cost	$39,063	Time	$0 /	$0 /	$0 /	$0 /	$0 /	$0 /	$0 /
	Energy cost	$2,162	Time	$0 /	$0 /	$0 /	$0 /	$0 /	$0 /	$0 /
	Material cost	$2,170	Quantity	$0 /	$0 /	$0 /	$0 /	$0 /	$0 /	$0 /
	Depreciation cost	$0		$0 /	$0 /	$0 /	$0 /	$0 /	$0 /	$0 /
	Others cost	$5,208	Length	$0 /	$0 /	$0 /	$0 /	$0 /	$0 /	$0 /
Monitoring staff	Personnel cost	$31,250	Time	$0 /	$3,906 / 1	$3,906 / 1	$0 /	$3,906 / 1	$3,906 / 1	$3,906 / 1
	Energy cost	$912	Time	$0 /	$114 / 1	$114 / 1	$0 /	$114 / 1	$114 / 1	$114 / 1
	Material cost	$2,170	Quantity	$0 /	$0 /	$0 /	$0 /	$0 /	$0 /	$2,170 / 1
	Depreciation cost	$0		$0 /	$0 /	$0 /	$0 /	$0 /	$0 /	$0 /
	Others cost	$5,208	Length	$0 /	$651 / 1	$651 / 1	$0 /	$651 / 1	$651 / 1	$651 / 1
	Others cost	$5,208	Time	$0 /	$0 /	$0 /	$744 / 1	$744 / 1	$744 / 1	$744 / 1
	Activity costs	$180,303		$4,125	$8,796	$8,796	$2,357	$7,028	$7,028	$9,198

As a result, as shown in Fig 5, the economic cost for an emergency response was simulated. In this case study, the average cost for one emergency response was "$ 89,080.4"; its standard deviation was "$ 566.4".

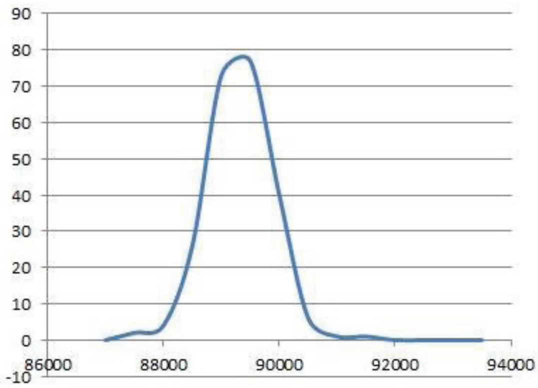

Fig. 5. Distribution curve of the simulated cost

5. Discussion

In this application, the economic cost for an emergency response in the elevator operation service was simulated. Based on the designed service process, economic costs of each entity were estimated, and then, the simulation model based on the components of STN was constructed. In the simulation model, the dynamics models of the variability of a cost driver were constructed. The result of the simulated cost enables the designers to evaluate the design solution from the viewpoint of the economic cost. For example, in this case study, the average cost for one emergency response was "$ 89,080.4"; its standard deviation was "$ 566.4". Since the distribution of the simulated costs corresponds to normal distribution, this result means that the economic cost of one emergency response will range from $ 88,514 to $ 89646.8 within 68.27 percent. Considering the probability of the occurrence of the emergency response additionally, the designers enable to determine the price of the contract for the service and/or evaluate the design solution from the viewpoint of the economic cost.

However, in this study, difficulties still remain with regard to the identification of stochastic elements within a service and modeling the variability of cost drivers that are influenced by these elements. To solve these problems, a method for the extraction of stochastic elements needs to be developed.

6. Conclusion

In this paper, a method for simulating the economic cost of a service in consideration of stochastic elements is proposed. According to the concept of Activity-Based Costing (ABC), the procedure for the construction of simulation model based on STN components is proposed. The application revealed that the proposed method is useful for designers to evaluate the economic cost of design solutions in consideration of stochastic elements within the service.

Future studies will include the development of method to extract stochastic elements within a service.

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